VISCOELASTIC SURFACTANT GELS WITH REDUCED SALT CONCENTRATION

Field of the Invention

The present invention relates to the use of organic compounds
for raising the viscosities and/or reducing the salt
requirements of viscoelastic surfactant (VES) gels, and
particularly organic compounds having one or more alcohol or
amine groups and compositions derived therefrom.

Background of the Invention

In the recovery of hydrocarbons, such as oil and gas, from
natural hydrocarbon reservoirs, extensive use is made of
wellbore treatment fluids such as drilling fluids, completion
fluids, work over fluids, packer fluids, fracturing fluids,
diverting fluids, acidising fluids, conformance or
permeability control fluids and the like.

In many cases significant components of wellbore fluids are
thickening agents, usually based on polymers or viscoelastic
surfactants, which serve to control the viscosity of the
fluids. Typical viscoelastic surfactants are N-erucyl-N,N-
bis(2-hydroxyethyl)-N-methyl ammonium chloride (known as
EHAC) and potassium oleate, solutions of which form gels that
are responsive to oil when mixed with aqueous brine.

The application of viscoelastic surfactants in both non-
foamed and foamed fluids used for fracturing subterranean
formations has been described in several patents, e.g. EP-A-
0835983, US-5258137, US-5551516, US-5964295 and US-5979557.

The use of viscoelastic surfactants for water shut off treatments is discussed in GB-A-2332224 and for selective acidizing in US 5,979,557 and Chang F.F., Love T., Affeld C.J., Blevins J.B., Thomas R.L. and Fu D.K., "Case study of a novel acid diversion technique in carbonate reservoirs", Society of Petroleum Engineers, 56529, (1999).

The salt concentration required to form the VES gels is typically between 3 and 12 weight percent. Figure 1 shows the measured rheological profiles of two VES gels based on EHAC and potassium oleate. The salt concentrations required for these systems are between 3 to 4 wt% and 6 to 8 wt%, respectively.

A general feature of VES gels is that the viscosity of the gel decreases with increasing temperature. In many cases the viscosity of the gel will show a decrease above a critical temperature. This effect can be clearly seen in Figure 1 where the viscosities of the gels decrease suddenly above about 60°C. In many hydrocarbon well applications, the downhole temperature can be above this critical temperature. When this happens, the performance of a treatment fluid based on the VES gel can be impaired.

Better performance can sometimes be achieved by increasing the brine concentration. But the transportation and handling of large volumes of salts for oilfield applications results in increased operational costs and potential health and safety implications. Due to these operational considerations, VES gels with a salt concentration of over 6% are rarely prepared in the field.

It is known in the art that the addition of an organic salt
(often termed a co-surfactant), as opposed to the more common
inorganic salt (such as KCl), to a surfactant can produce a
VES gel at a lower concentration of added salt. However,
these organic-salt gel systems can have little or no
tolerance of the introduction of any other type of salt.
This often results in the formation of a precipitate or phase
separation in use which limits the operational effectiveness
of these systems. A review of organic-salt VES systems has
been published by Hoffmann and Ebert [Angew. Chem. Int. Ed.
Engl., 27, 902-912 (1988)].

The use of long-chain alcohols in conjunction with
surfactants has been reported in the literature. A cubic
phase of vesicles was formed when octanol and sodium oleate
were mixed in water with a relative ratio of 2:1 (see
Gradzielski, M., Bergmeier, M., Muller, M., and Hoffmann, H.
"Novel gel phase: A cubic phase of densely packed
monodisperse, unilamellar vesicles", *J. Phys. Chem.*, 101,
1719 (1997)). However, this is not of a worm-like micellar
type gel and is not as responsive to hydrocarbons. The gel
formed from cetyl pyridinium chloride and NaCl is weakened
upon the addition of 4-propyl phenol and further addition of
the alcohol results in phase separation (see Rehage, H. and
Hoffmann, H., "Viscoelastic surfactant solutions:model
systems for rheological research", *Mol. Phys.*, **74**, 933
(1991).

Patist et al. have observed that long-chain alcohols have an
effect upon the NMR relaxation time of spherical micelles
(Patist, A., Axelberd, T., and Shah, D.O., "Effect of long
chain alcohols on micellar relaxation time and foaming
properties of sodium dodecyl sulfate", *J. Coll. Int. Sci.*,

208, 259 (1998)). They postulate that the sodium dodecyl sulfate micelles pack more tightly when the alcohol is present.

5   It is also known to dilute VES-based treatment fluids with alcohol (see e.g. US 5,551,516 and US 6,239,183). However, alcohol additions of this type are typically made with the aim of producing a suitable surface viscosity for injection. The effect of such additions on the downhole rheological

10   performance of VES gels has not been investigated. Furthermore, WO 01/77487 describes the use of an alcohol or amine additive to reduce the viscosity of a viscoelastic surfactant based fluid. As is described therein, above a critical concentration, specific to the alcohol or amine

15   additive, the addition of the alcohol or amine may *reduce* the viscosity of the gel. This critical alcohol or amine concentration depends on temperature such that typically a lower critical concentration is observed at elevated temperature. In this situation, a precursor is used to

20   slowly release a concentration of the alcohol which is above the critical concentration, thereby reducing the viscosity.

Summary of the Invention

25   The present invention is at least partly based on the discovery that the temperature at which the viscosity of a VES gel decreases can be increased by the addition of an alcohol or amine. It was also discovered that such an addition can cause an increase in the viscosity of the VES

30   gel.

Accordingly, a first aspect of the present invention provides a wellbore fluid and its use including an organic compound

having one or more polar groups to raise the critical
temperature of a VES gel useful in a wellbore treatment
fluid.

5   Thus the organic compound can be used to extend the range of
downhole operating temperatures under which VES gels can be
usefully employed.

A second aspect of the present invention provides the use of
10   an organic compound having one or more alcohol or amine
groups to reduce the concentration of inorganic salt that
raises the viscosity of a VES gel above a level useful in a
wellbore treatment fluid.

15   In a further embodiment of this aspect of the invention, in a
VES gel comprising an inorganic salt, the present invention
provides the use of an organic compound having one or more
alcohol or amine groups to reduce or substantially eliminate
the amount of that salt. The salt concentration of the well
20   bore fluid in wt% preferably ranges between 0 and 6, more
preferably between 0 and 4 and even more preferable between 0
and 3, or even under 3 using for example fresh water instead
of brine. The above salt concentration may include organic
salts.

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Advantageously, the organic compound used in this way allows
the inorganic salt requirements of VES gels to be reduced.
Indeed, under certain circumstances, the useful viscosity
level can be achieved in the absence of inorganic salt.

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Furthermore, the first and second aspects can be combined and
an organic compound having one or more alcohol or amine
groups can be used to both raise the temperature at which the

viscosity of a VES gel falls below a level useful in a
wellbore treatment fluid, and to reduce the concentration of
inorganic salt required to raise the viscosity of a VES gel
above that level.

A further aspect of the present invention provides a method
of treating a subterranean formation of a hydrocarbon well
comprising injecting a treatment fluid into the well, the
fluid comprising a surfactant for forming a VES gel, an
organic compound having one or more alcohol or amine groups,
and optionally an inorganic salt; whereby the organic
compound raises the temperature at which the viscosity of the
VES gel falls below a level useful for treating a
subterranean formation of a hydrocarbon well, and/or reduces
the concentration of inorganic salt required to raise the
viscosity of the VES gel above that level.

The wellbore treatment fluid may be e.g. a fracturing fluid,
a selective acidising fluid or diverting fluid, or a water
shut-off fluid. Fracturing fluids are used to create opening
or cracks in the formation and carry components such as
proppants to prevent the openings from closing. Diverting
fluids are fluids that inhibit access of subsequently
injected fluids, such as acidising fluids, into formation
layers with low oil saturation.

The following optional features and preferred embodiments
relate to any of the previous aspects of the invention.

The viscosity level useful for most well bore applications,
including for example fracturing fluids, is generally between
50 and 100 cP at a shear rate of 100 s^{-1}. Fluids in
accordance with the present invention may exhibit viscosities

of 50 cP or 60 cP at temperatures above 50 degrees Celsius, or above 60 degrees Celsius and even above 70 degrees Celsius without increasing the salt level above 6 wt%.

5   The useful viscosity level should be attained at a broad range of reservoir temperatures. Typically reservoir temperatures can range from around 30°C to around 200°C. Using the present invention, the critical temperature before significant loss of viscosity occurs, can be raised to above

10 100, 130 and even 150 degrees Celsius without turning to high salt concentrations.

The low shear viscosity level useful for effective transport

15 of proppant particles is suitably >1000 cP at less than or equal to 1 s^{-1}.

The viscosity level of a diverting gel useful for VES diversion systems is suitably >20 cP at 100 s^{-1}.

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The viscosity level useful for water control treatments is typically <100 cP at encountered shear rates.
The organic compound may be suitably miscible with the VES gel formulation and it is typically non-ionic.

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The organic compound may be composed of a linear or branched saturated or partially unsaturated carbon chain comprising one or more polar groups, wherein the polar groups are typically -OH, -SH or -NH$_2$. As the observed effect becomes

30 more pronounced at high molecular weight, the organic compound may be preferably selected from a range comprising between 7 and 22 carbon atoms or more preferably comprising between 7 and 16 carbon atoms.

The organic compound may contain at least one other group
selected from an ether, ketone, amide, ester, phosphate ester
or phosphonate ester group.

The organic compound may be a mono-alcohol, a diol, an
ethoxylated alcohol, ethyoxylated amine, alkanolamide or
fatty acid ethoxylate, for example propan-2-ol, butanol,
octan-1-ol, oleyl alcohol, versatyl alcohol, butanediol,
butyl amine, oleyl amine or a dimeric oleyl amine.
The VES gel may be formed from a surfactant which is anionic,
cationic or zwitterionic, and is, for example, a carboxylate
or modified carboxylate, a compound of formula R-X-Y-Z (as
hereinafter defined), a quaternary ammonium compound, an
alkyl betaine/sulphobetaine or an alkyl amido betaine/sulpho-
betaine. Preferably the surfactant is derived from oleic
acid, linoleic acid or mixtures thereof, erucic acid, tallow
acid, dimeric/trimeric/oligomeric carboxylic acids; or is
E1018, oleyl ester succinate, oleyl amide succinate, oleyl
sarcosinate or N-erucyl-N,N-bis(2-hydroxyethyl)-N-methyl
ammonium chloride.

Preferably, the molar ratio, the ration between the
concentration measured in mol/l, of the organic compound to
the surfactant on which the VES gel is based is 0.5 or less.
More preferably, the molar ratio is in the range of 0.05 to
3, and even more preferably in the range of 0.05 to 2.

Brief Description of the Drawings

Figure 1 - Rheological profile as a function of temperature
of 4 wt% N-erucyl-N,N-bis(2-hydroxyethyl)-N-methyl-

ammoniumchloride (EHAC) and 4 wt% potassium oleate gels with respectively 3 and 8 wt% KCl.

Figure 2 - Rheological profile as a function of temperature
of two 4 wt% dimeric surfactant gels with respectively 4 and
8 wt% KCl.

Figure 3 - Rheological profile as a function of temperature
of two 4 wt% dimeric surfactant gels, both with 4 wt% KCl and
one with 0.3 molar ratio of oleyl alcohol.

Figure 4 - Rheological profile as a function of temperature
of two 4 wt% monomeric amide surfactant gels with and without
0.1 molar ratio of oleyl alcohol.

Figure 5 - Rheological profile as a function of temperature
of three 4 wt% oleyl sarcosinate gels, one without alcohol,
and the other two with respectively 0.3 molar ratio of 1-
octanol and 0.15 molar ratio of oleyl alcohol.

Figure 6 - Rheological profile as a function of temperature
two 4 wt% oleyl sarcosinate gels with and without 0.1 molar
ratio of oleyl amine.

Figure 7 - Rheological profile as a function of temperature
of four 4 wt% oleic acid dimer (E1018, supplied by Cognis
Oleochemicals) gels, three with 6 wt% and one with 8 wt% KCl.
Two of the gels with 6 wt% KCl also contain 0.15 molar ratio
of respectively oleyl alcohol and 1-octanol.

Figure 8 - Low shear viscosity of viscoelastic gels based on
3.375 wt% EHAC with and without 1.125 wt% iso-propanol (IPA)
as a function of salt (KCl) concentration and temperature.

Figure 9 - Variation of KCl concentration required to produce
an optimum viscosity, against temperature for two VES gels
based on 3.375 wt% EHAC with and without the addition of
1.125 wt% IPA.

Figure 10 - Viscosity at 80˚C as a function of shear rate
(0.1-100s^{-1}) of a 4 wt% oleyl ester succinate / 1.5 wt% KCl
gel with and without 0.1 molar ratio oleyl alcohol.

Figure 11 - Rheological profile as a function of temperature
of three gels based on Edenor UKD™ (supplied by Cognis
Oleochemicals), one gel containing 2.5 wt% Edenor™ and 3 wt%
KCl, another gel containing 2 wt% Edenor™ and 3 wt% KCl and
0.5 wt% oleyl diethanolamide, and the last gel containing 2
wt% Edenor™ and 10 wt% KCl.

Detailed Description of the Invention

In conventional treatment fluids based on VES gels, the
temperature dependence of the viscosity may be controlled to
some extent by varying the concentration of salt in the VES
gel. Figure 2 (discussed more fully below in relation to
Example 1) shows the effect of varying the salt concentration
on the rheological properties of a VES gel. It can be seen
that raising the salt concentration in the gel increases the
critical temperature of the VES gel. However, as illustrated
by Figure 8 (discussed more fully below in relation to
Example 7), the viscosity tends to drop off beyond a certain
salt concentration.

The viscosity level of a wellbore treatment fluid, and in
particular of such a fluid useful for treating a subterranean

formation of a hydrocarbon well will depend on the type of treatment. The viscosity of a VES-based fracturing fluid should be 50-100cP at 100s-1, preferably >75cP at 100s-1. In order to transport proppant particles effectively, the

5   fracturing fluid should also have a much higher low shear viscosity, typically >1000cP at <1s-1. For VES diversion systems, the viscosity of the diverting gel should be greater than about 30cp at 100s-1 and preferably about 50cP at 100s-1. For treatments where the fluid is required to penetrate

10   rock matrix, e.g. water control treatments, then the typical fluid viscosity during injection should be <100cP and preferably <50cP throughout the range of shear rates encountered during placement.

15   Generally, a VES gel-based fluid will display an optimum salt concentration at which the critical temperature shows a maximum. This optimum salt concentration is often above the 6 wt% commonly achievable in oilfield operations and may, in some cases be above 12 wt%.

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In VES gels according to the present invention, the addition of an organic compound such as an alcohol or amine to the VES gel has the effect of increasing the critical temperature of the gel.

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Alternatively or additionally the addition of an organic compound such as an alcohol or amine reduces or possibly substantially eliminates the salt requirement of the gel. In many cases this allows gels to be formed with similar

30   viscosities to those achieved with the optimum salt concentration in the absence of the organic compound.

The effects of raising the critical temperature of a VES gel
and reducing or substantially eliminating the salt
requirement by addition of an organic compound such as an
alcohol or amine extend across a wide range of such organic
5   compounds.

As used herein, "critical temperature" means the temperature
above which the viscosity of the gel ceases to be useful for
a wellbore treatment fluid and in particular for the
10   treatment of a subterranean formation of a well. The
critical temperature will vary depending on the exact
composition of the VES gel, but can be determined for a
particular gel using techniques known and available in the
art.

15

The organic compound is typically a compound which is
miscible with the VES gel formulation and which either
resides mainly in the continuous aqueous phase of the fluid
or at least partially resides within the worm-like micellar
20   phase of the fluid. If the compound is too hydrophobic, then
a low molar ratio of the compound will migrate to the
interior of the worm-like micelles causing the worm-like
micellar structure to be broken resulting in a *reduction* in
the viscosity of the fluid at ambient temperature. Relative
25   to the latter behaviour, the preferred compounds are more
hydrophilic such that a molar ratio of the compound to the
surfactant <0.5 or preferably <0.3 or more preferably ≤0.1
does not cause the worm-like structure of the fluid to break,
but rather it enhances the viscosity at elevated temperatures
30   and it also reduces the concentration of inorganic salt which
is required to optimize the high temperature tolerance of the
gel.

The organic compound is preferably non-ionic. Typically it
may be composed mainly of a linear or branched saturated or
partially unsaturated carbon chain with a sufficient number
of polar groups to impart a hydrophilic-lipophilic balance

5   (HLB) high enough to render the compound miscible with the
aqueous VES gel formulation and high enough such that low
molar ratios of the compound do not break the worm-like
micellar structure of the VES gel. Typical polar group(s) of
the compound are -OH, -SH, -NH$_2$. The compound may also

10 contain other groups such as ether, ketone, amide, ester,
phosphate ester or phosphonate ester groups. Thus, when the
compound contains -OH groups, it can be a simple mono-alcohol
such propan-2-ol, butanol, octan-1-ol or oleyl alcohol, an
alpha-branched alcohol such as versatyl alcohol, a diol such

15 as butanediol or a more complex molecule such as an
ethoxylated alcohol, ethoxylated amine, alkanolamide or fatty
acid ethoxylate. Dimeric or oligomeric forms such as a dimer
acid ethoxylate may also be used. When the compound is more
hydrophilic and completely miscible with the continuous

20 phase, e.g. propan-2-ol or butanediol, then the compound can
be symmetric or asymmetric. When the compound is more
hydrophobic, e.g. octan-1-ol or oleyl alcohol, then the
compound is asymmetric such that it can penetrate the worm-
like micelles. When the compound does not contains -OH

25 groups, it can be an amine such as butyl amine, oleyl amine
or a dimeric oleyl amine.

For VES treatment fluids formed with alcohol and amine
additives, the concentrations of additive required to elevate

30 the critical temperature are similar. In each case, the
molar ratio of the additive to the surfactant which forms the
VES gel may be 0.5 or less, and more preferably the molar
ratio is in the range from 0.01 and 0.4.

The VES gel may be formed from a surfactant which is anionic, cationic or zwitterionic. Typical anionic viscoelastic surfactants include carboxylates and modified carboxylates

5   where the typical carboxylates can be those derived from oleic acid, linoleic acid, erucic acid, mixtures of oleic and linoleic acid, tallow acid, dimeric/trimeric/oligomeric carboxylic acids and where the modified carboxylates can be ethoxycarboxylates, ester carboxylates or amide carboxylates.

10 Exemplary modified carboxylates include oleyl ester succinate, oleyl amide succinate and oleyl sarcosinate. When the viscoelastic surfactant is anionic, it may be of general formula R-X-Y-Z (as described in WO/02/064945 and WO/02/064947) and in which R is the hydrophobic tail of the

15 surfactant, Z is the hydrophilic head of the surfactant, said hydrophilic head group being charged, X is a stabilising group and Y is a linear, saturated or unsaturated chain of 1, 2 or 3 carbon atoms or a branched, saturated or unsaturated hydrocarbon chain wherein the main chain is of 1, 2 or 3

20 carbon atoms, possibly incorporating an aromatic ring. Preferably the anionic group Z can be carboxylate, COO⁻ or sulphonate, SO$_3^-$.

Typical cationic surfactants include quaternary ammonium

25 compounds such as N-erucyl-N,N-bis(2-hydroxy-ethyl)-N-methyl ammonium chloride. Typical zwitterionic surfactants include the alkyl betaines/sulphobetaines and alkyl amido betaines/sulphobetaines where the alkyl group is typically oleyl or erucyl and dimeric/trimeric/oligomeric forms of

30 these betaines/sulphobetaines.

Preferred VES surfactants to which the present invention may be applied include conventional commercially available

surfactants, such as oleyl ester succinate, oleyl amide
succinate, dimeric oleyl amide succinate, oleyl sarcosinate,
oleic acid salt, oleic acid salt dimer, EHAC and a mixture of
linoleic and oleic acids, as well as e.g. the surfactant
compounds (I-VII) shown below which are intended to have
extended temperature capabilites.

Compound I is oleyl ester succinate (reverse ester bond).
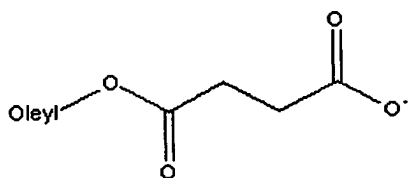Compound II is oleyl ester glutarate (reverse ester bond).
Compound III is erucyl amide succinate (reverse amide bond).
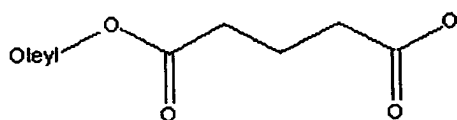Compound IV is erucyl amide succinate (forward amide bond).
Compound V is oleyl amide succinate (reverse amide bond).
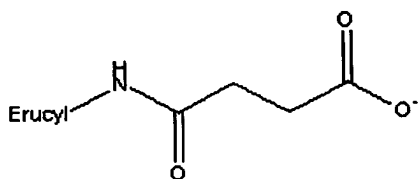Compound VI is oleyl amide succinate (forward amide bond).
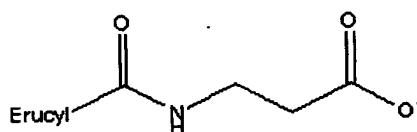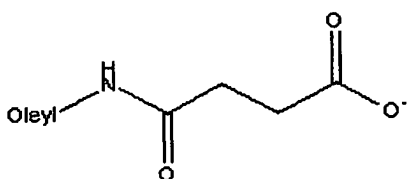Compound VII is dimer-(oleyl amide succinate (reverse amide
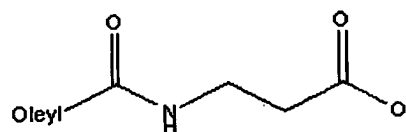

Compound I
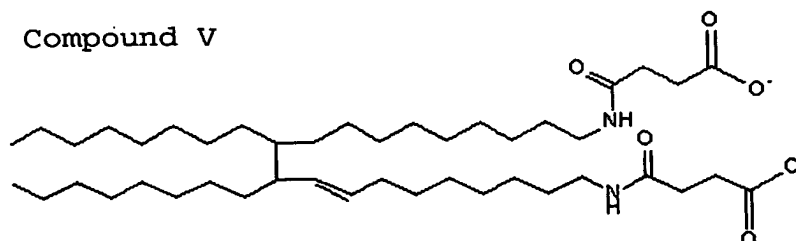

Compound II

Compound III

Compound IV

Compound V

Compound VI

Compound VII

bond)).

VES-based treatment fluids according to the present invention
show wide applicability in wellbore applications. The fluids
5   may be used as, for example, fracturing fluids, selective
acidising fluids; water shut-off fluids, well clean-out
fluids, diversion fluids for acid and scale dissolver
treatments. VES-based treatment fluids of the present
invention are particularly useful in the treatment of a
10   subterranean formation of a well.

VES gel treatment fluids of the present invention may be
formulated by simple admixing of the VES surfactant with an
appropriate alcohol or amine additive. In some embodiments
15   of the invention, the treatment fluid may also comprise other
elements such as a proppant, if the gel is formulated as a
fracturing fluid, such as 20-40 mesh sand, bauxite, glass
beads etc.

20   The alcohol or amine additive may be pre-mixed with the
surfactant to a given concentration. This facilitates
transport of the alcohol or amine additives to oilfield
sites. When on site, water or aqueous salt solution (usually
KCl brine) is added to the pre-mixed surfactant-alcohol/amine
25   to formulate the treatment fluid.

Alternatively, the alcohol or amine additive may be mixed on-
site with the surfactant and water/brine to form the
treatment fluid.

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The performance of VES surfactant systems according to the
present invention have been assessed in terms of the rheology

(variation of viscosity with temperature or salt concentration) of the respective gel.

A controlled stress rheometer (Bohlin model type CVO-50) was used to measure the rheological properties of the solutions. Using a concentric cylinders (Couette) geometry (inner radius of the outer cylinder, R_i = 1.375 cm, outer radius of the inner cylinder, R_o = 1.25 cm, and inner cylinder length = 3.78 cm), corresponding to the geometry of German DIN standard 53019, the viscosity of each gel was measured at a particular shear rate.

For the particular geometry of the rheometer, the shear rate was calculated as:

$$\dot{\gamma} = \frac{RPM.2\pi}{60} \frac{2.R_i^2 R_o^2}{\left(\frac{R_i + R_o}{2}\right)^2 \left(R_o^2 - R_i^2\right)} ,$$

where RPM is the rotational speed (in revolutions per minute) of the inner cylinder. The viscosity was then obtained for each measurement by dividing the measured stress by the calculated shear rate.

Example 1
A surfactant derived from dimeric oleyl amide succinate forms a gel when it is dissolved in aqueous base and salt is added. In a VES gel containing 4 wt% oleyl amide succinate and aqueous KCl, the optimum salt concentration is around 8 wt% KCl. At this salt concentration, the temperature at which the viscosity of the gel drops below 50 cp is just over 130°C. This temperature drops dramatically to just over 70°C if only 4 wt % KCl is added. This effect can be seen in Figure 2. The temperature at which the viscosity of the gel drops below 50 cp is raised when a 0.3 molar ratio of oleyl

alcohol is added. This effect can be seen in Figure 3 where
the temperature at which the viscosity of the gel drops below
50 cp is approximately 60°C with no alcohol added as compared
to approximately 100°C for the gel containing 0.3 molar ratio

5   oleyl alcohol. The gel with 4 wt% KCl and a 0.3 molar ratio
of oleyl alcohol performs almost to the level of the
optimized system which has 8 wt% KCl as shown in Figure 2.
This effect can be used to maintain performance of these VES
gels whilst also lowering the salt requirements for their

10   formation to 6 wt% which is achievable in oilfield
applications.

Monomeric oleyl amide succinate shows similar behaviour to
that of its dimeric counter-part in forming VES gels on

15   addition of aqueous base and a salt. The rheological
performance of the monomeric version of oleyl amide succinate
is shown in Figure 4. The optimum salt concentration for
this VES system is 10 wt% and again, a dramatic loss of
performance is observed when the salt concentration is

20   reduced to 4 wt%. Addition of a 0.1 molar ratio of oleyl
alcohol increases the temperature at which the system has gel
properties, therefore increasing the application range of the
material.

25   *Example 2*
The method of Example 1 is also applicable to other amide
systems, such as oleyl sarcosinate (commercially available
from Dow chemicals and known as Hamposyl O). A 4 wt%
solution of the amide requires 10 wt% KCl to remain as a gel

30   up to around 100°C. The viscosity of the same material with
only 6 wt% KCl loses its gel properties at just under 80°C.
The addition of a 0.15 molar ratio of oleyl alcohol to the
gel containing 6 wt% KCl restores the temperature at which

the viscosity falls below 50 cp to around 95°C. The
rheological profile is shown in Figure 5.

This phenomenon is not only related to oleyl alcohol. On
addition of a 0.3 molar ratio of 1-octanol to the VES system
containing 6 wt% KCl, the temperature at which the viscosity
of the gel falls below 50 cp is restored to around 90°C
compared to just under 80°C in the absence of 1-octanol. The
effect of adding the 1-octanol to the oleyl sarcosinate gel
containing 6 wt% KCl is shown in Figure 5.

Furthermore, on addition of a 0.1 molar ratio of oleyl amine
to the VES system containing 6 wt% KCl, the temperature at
which the viscosity of the gel falls below 50 cp is restored
to around 85°C. The rheological profile for this system is
shown in Figure 6.

Example 3
VES gels derived from the salts of oleic acid dimers have
also been examined. The KCl concentration required to
achieve optimum performance for these systems is around 8
wt%. VES gels based on one of these oleic acid dimers, E1018
(supplied by Cognis) is of interest due to its reasonable
tolerance to the presence of divalent cations such as
calcium. The gel formed from this blend of oligomeric acids
(E1018) has an upper operating temperature of around 90°C.
This temperature drops to below 80°C when the KCl
concentration is reduced to the 6 wt% which is manageable in
the field. However, the temperature at which the viscosity
of a gel formed form E1018 with 6 wt% KCl falls below 50 cp
can be raised to around 90°C by the addition of a 0.15 molar
ratio of an alcohol such as 1-octanol or oleyl alcohol. This
effect is shown in the rheological profile of Figure 7.

It can be seen in Figure 7 that the performance of the VES
gel formed from E1018 with 6 wt% KCl and 0.15 molar ratio of
either oleyl alcohol or 1-octanol is comparable to that of a
gel formed from E1018 with 8 wt% KCl. The lowering of the
salt requirements to 6 wt% or below makes these gels more
practical to use in the field.

Example 4

N-erucyl-*N,N-bis*(2-hydroxyethyl)-*N*-methylammonium chloride
(EHAC) forms VES gels in the presence of chloride salt
solutions (see Figure 1). However, the concentration of salt
required to form the strongest gel is reduced when iso-
propanol is added to the system.

A range of VES gels were formulated with 3.375 wt% EHAC and
varying overall concentrations of KCl. The viscosity of
these gels was tested at each of 40, 60, 80, and 100°C. The
results of these tests are shown in Figure 8 as the solid
lines of the rheological profiles. It can be seen from
Figure 8 that this gel system shows a definite optimum salt
concentration which results in the highest viscosity at each
temperature tested. For the gels containing only EHAC and
KCl, the optimum salt concentration lies between 4 and 6 wt %
depending upon the temperature of the gel.

A second range of VES gels was then formulated again with
3.375 wt% EHAC and varying overall concentrations of KCl but
now with an additional 1.125 wt% iso-propyl alcohol (IPA).
The viscosity of these gels was tested at each of 40, 60, 80,
and 100°C. The results of these tests are shown in Figure 8
as the dashed lines of the rheological profiles. It can be
seen that in each case, the addition of IPA results in the

optimum salt concentration at which the highest viscosity is
achieved being shifted to lower values. In addition, the
maximum viscosity achieved at each of the temperatures tested
is higher in the gels containing IPA than in those with only

5   EHAC and KCl.

The effect of adding 1.125 wt% IPA to the 3.375 wt% EHAC
solution is shown in Figure 9. From this figure it can be
seen that the addition of 1.125 wt% IPA to the EHAC based VES

10   gel results in the lowering of the optimum KCl concentration
by between 2 and 2.5 wt%.

Example 5
Two VES gels were formulated, the first using 4 wt% oleyl

15. ester succinate surfactant and 1.5 wt% KCl and the second the
same but including 0.1 molar ratio or oleyl alcohol. The
viscosity at 80°C of the gels is shown in Figure 10 as a
function of shear rate (0.1-100s^{-1}). It can be seen that the
viscosity of the VES gel containing oleyl alcohol is higher

20   than that without the added alcohol with increasing shear
rates.

Example 6
A commercial mixture of linoleic and oleic acids (sold under

25   the name Edenor™) is known to form VES gels on addition of
aqueous KCl. Without other additions, around 10 wt% KCl is
required to give optimum temperature performance. Figure 11
shows the rheological profile of two Edenor-based VES gels
with respectively 3 and 10 wt% KCl added and a further gel

30   which contains 0.5 wt% oleic diethanolamide and 3 wt% KCl.
It can be seen in Figure 11 that the viscosity of the VES gel
with 10 wt% added KCl drops below the 50 cp threshold at just

over 80°C. If the gel contains only 3 wt% KCl, this temperature is lowered dramatically to about 35°C. However, when 0.5 wt% oleic diethanolamide is added to the gel with 3 wt% KCl, this temperature recovers to almost the same level as the gel with 10 wt% KCl.

While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure. Accordingly, the exemplary embodiments of the invention set forth above are considered to be illustrative and not limiting.